

# Measurement of $^{25}\text{Mg}(p, \gamma)^{26}\text{Al}$ resonance strengths via gamma spectrometry

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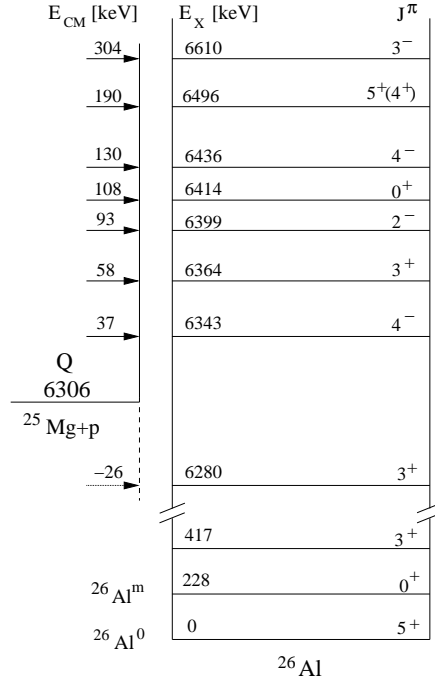
**Abstract.** The COMPTEL instrument performed the first mapping of the 1.809 MeV photons in the Galaxy, triggering considerable interest in determining the sources of interstellar  $^{26}\text{Al}$ . The predicted  $^{26}\text{Al}$  is too low compared to the observation, for a better understanding more accurate rates for the  $^{25}\text{Mg}(p, \gamma)^{26}\text{Al}$  reaction are required.

The  $^{25}\text{Mg}(p, \gamma)^{26}\text{Al}$  reaction has been investigated at the resonances at  $E_r \dagger = 745, 418, 374, 304$  keV at Ruhr-Universität-Bochum using a Tandem accelerator and a  $4\pi$  NaI detector. In addition the resonance at  $E_r = 189$  keV has been measured deep underground laboratory at Laboratori Nazionali del Gran Sasso, exploiting the strong suppression of cosmic background. This low resonance has been studied with the 400 kV LUNA accelerator and a HPGe detector. The preliminary results of the resonance strengths will be reported.

## 1. The $^{25}\text{Mg}(p, \gamma)^{26}\text{Al}$ reaction

The  $^{25}\text{Mg}(p, \gamma)^{26}\text{Al}$  is the slowest reaction of the Mg-Al cycle. The  $^{26}\text{Al}$  ground state ( $T_{1/2} = 7 \cdot 10^5$  yr) decays via  $\beta^+$  and EC to the the  $2^+$  first excited state of  $^{26}\text{Mg}$ . This

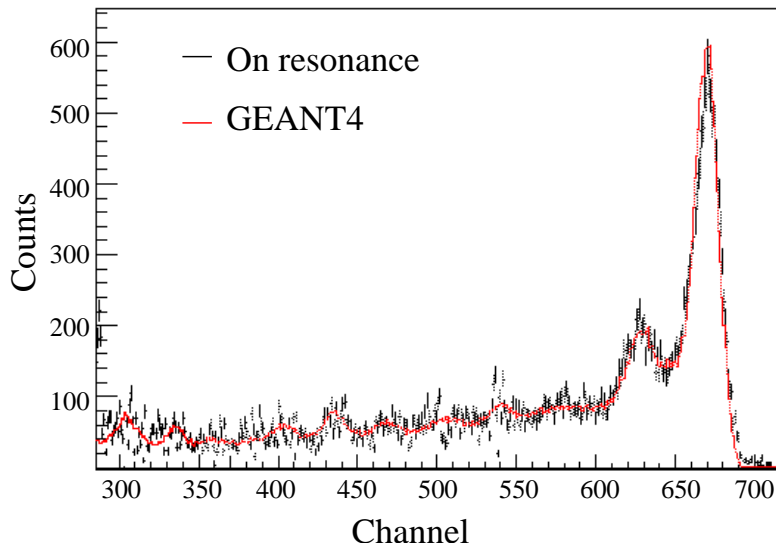
$\dagger$  As a general notation in this work,  $E_r$  is the resonance energy in the center of mass system.



**Figure 1.** Level scheme of  $^{26}\text{Al}$ .

level decays to the ground state of  $^{26}\text{Mg}$  with the emission of a 1.809 MeV  $\gamma$ -ray, one of the most important lines in  $\gamma$  astronomy. The direct observation of this radiation from COMPTEL [2] and INTEGRAL [3] instruments provides an evidence that  $^{26}\text{Al}$  production is still active on a large scale. Moreover, the observation of  $^{26}\text{Mg}$  isotopic enrichment (extinct  $^{26}\text{Al}$ ) in carbonaceous meteorites [1] shows that the  $^{26}\text{Al}$  had been produced before the formation of the solar system ( $4.6 \times 10^9$  yr). Any astrophysical scenario must be concordant with both observations. Stellar nucleosynthesis studies have not yet identified which one of the possible  $^{26}\text{Al}$  sources could explain the observed evidences. Existing stellar models predict that 30-50% of the production of  $^{26}\text{Al}$  comes from hydrogen-burning shell (HBS) of massive stars (core collapse Supernovae and Wolf-Rayet stars). The remaining should come elsewhere, for example from HBS of low mass AGB or from the nucleosynthesis of Novae. Hence, solving the controversy for different astrophysical production sites of  $^{26}\text{Al}$  demands a better understanding of the rates for the  $^{25}\text{Mg}(p, \gamma)^{26}\text{Al}$  reaction.

Figure 1 shows the level scheme of  $^{26}\text{Al}$ . The Q-value of the reaction is  $Q = 6306$  keV. Any internal transition from the isomeric state  $^{26}\text{Al}^m$  ( $T_{1/2} = 6.35$  s) to the ground state of  $^{26}\text{Al}$  are inhibited due to the large spin difference. In the past the levels down to 6496 keV, corresponding to the resonance  $E_r = 189$  keV have been directly and indirectly studied [4, 5, 6, 7]. A recent publication by Arazi et al. [8] making use of the AMS technique gives resonance strengths down to the resonance energy at  $E_r = 189$  keV. The main difference, between AMS results and the previous data in literature, concerns the value of the resonance strength at  $E_r = 189$  keV, where Arazi et al. [8] quoted a value about 5 times smaller than the value published previously [9, 6].

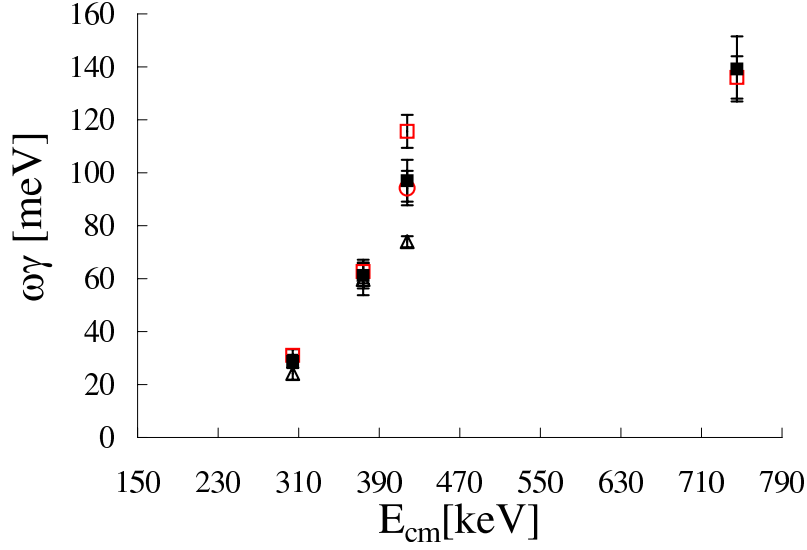


**Figure 2.** Comparison between experimental spectrum (black curve) acquired at  $E_r = 304$  keV and a simulated one (red curve).

## 2. Measurements of $^{25}\text{Mg}(p, \gamma)^{26}\text{Al}$ strengths

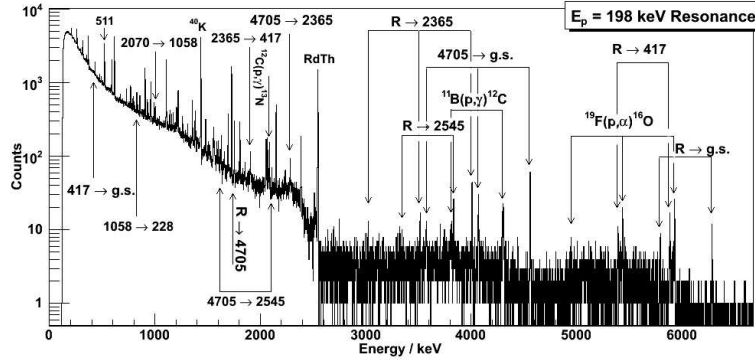
In the framework of LUNA, the resonances at  $E_r = 304$ , 374, 418, and 745 keV have been investigated [10] at Ruhr-Universität-Bochum using the 4MV Dynamitron-Tandem accelerator, with an average proton beam current of 100nA, and a 12" x 12"  $4\pi$  NaI summing crystal [11]. The Mg targets have been produced evaporating MgO powder isotopically enriched in  $^{25}\text{Mg}$  (98%) on Ta backing. The same technique for target production was also used for low energy measurements. The efficiency in the energy range  $3000\text{keV} < E_\gamma < 7000\text{keV}$  was determined to be about 70% using a Monte Carlo code based on Geant4 [12] simulation. In the simulation the branching ratios of the resonances and known levels in  $^{26}\text{Al}$  from literature [13, 6] have been used to reproduce the complex decay scheme of the  $^{25}\text{Mg}(p, \gamma)^{26}\text{Al}$  reaction. In this way the simulated  $\gamma$ -spectra could be directly fitted to the experimental spectra and no additional information about average multiplicity was necessary (see e.g. [14]). The uncertainty of this procedure was estimated by varying the branching ratios in a reasonable range [10]: no significant influence was observed. The code was tested with calibrated sources [10] and, moreover, a perfect agreement with the results of [11] was obtained. A detailed discussion of these measurements will be presented in a forthcoming article [15]. Figure 2 shows a comparison between the experimental spectrum recorded at  $E_r = 304$  keV, and a simulated one. The strength values are shown in fig. 3. The  $\omega\gamma$  results are in good agreement with previous work in particular [7, 6] and disagree with [8].

In addition, the resonance at  $E_r = 189$  keV has been investigated using the 400kV LUNA accelerator facility installed in a deep underground laboratory in the Laboratori Nazionali del Gran Sasso. The peculiarities of this accelerator have been described elsewhere [16]. The detector used was a HPGe detector (119% efficiency), placed at  $\theta = 55^\circ$  relative to the beam direction. The distance between the target and the



**Figure 3.** Resonance strengths versus the energy in the center of mass. Filled in data points are the results from Bochum analysis [10], the open triangles are from AMS measurements [8], the open square are from Nacre compilation [9], and the open circle is the experimental value measured by Powell et al. [7].

front face of the detector was 3.5 cm, in order to guarantee a high detection efficiency. Due to this geometry significant corrections due to the summing effect had to be applied. The efficiency curve for the measurement of the  $E_r = 189$  keV resonance energy was determined using the  $^{14}\text{N}(p,\gamma)^{15}\text{O}$  ( $E_r = 259$  keV) and  $^{24}\text{Mg}(p,\gamma)^{25}\text{Al}$  ( $E_r = 224$  keV) reactions as well as  $^{137}\text{Cs}$  and  $^{207}\text{Bi}$  calibrated sources. Spectra were collected with the detector at three different distances from the target, with the aim of investigating in detail the summing in and the summing out effects. In order to prevent build-up of impurities on the target, a LN-cooled trap was mounted directly to the front face of the target. Repeated measurement of the resonance profile during long-term high beam bombardments (average current  $250\mu\text{A}$ ) allowed for monitoring the  $^{25}\text{Mg}$  target quality and purity. Figure 4 shows the experimental spectrum acquired at  $E_r = 189$  keV with a total charge of 25C. This set-up improves the knowledge of the  $\gamma$ -ray cascade structure of the resonance. We observed the complex  $\gamma$ -ray cascade including the transition to the ground state. We also were able to identify the principal background contamination reactions:  $^{11}\text{B}(p,\gamma)^{12}\text{C}$  and  $^{19}\text{F}(p,\alpha\gamma)^{16}\text{O}$ . After a preliminary analysis we are able to quote the branching ratio for the ground state transition to be 6%. Due to the difficulties in the determination of summing out correction, we are able to give a preliminary range for the resonance strength at  $E_r = 189$  keV,  $6.8 \times 10^{-7} \text{eV} < \omega\gamma < 7.7 \times 10^{-7} \text{eV}$ . This range is in perfect agreement with the value given by Iliadis et al  $(7.4 \pm 1.0) \times 10^{-7} \text{eV}$  [6]. The analysis of the full data set is still in progress, as well as a new  $\gamma$ -measurement with a BGO summing crystal at LNGS, aiming the first direct detection of the resonance at  $E_r = 93$  keV.



**Figure 4.** Underground  $\gamma$ -spectrum of the  $^{25}\text{Mg}(p, \gamma)^{26}\text{Al}$  reaction recorded at resonance energy  $E_r = 189$  keV.

### 3. Acknowledgments

”We would like to thank Helmut Baumeister, University of Münster (Germany) and Massimo Loriggiola, INFN Laboratori Nazionali di Legnaro (Italy) for the Magnesium target production. This work was supported by INFN and in part by the European Union (TARI RII3-CT-2004-506222), the Hungarian Scientific Research Fund (K68801 and T49245) and the Deutsche Forschung Gemeinschaft (DFG) (Ro429/41).”

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